Renewable and Sustainable Energy Reviews 15 (2011) 4443–4450

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Using real option analysis for highly uncertain technology investments: The case of wind energy technology

Shun-Chung Lee*

Taiwan Institute of Economic Research, 7F., No. 16-8, Dehuei Street, Jhongshan District, Taipei 104, Taiwan

ARTICLE INFO

Article history:
Received 17 March 2011
Accepted 18 July 2011
Available online 15 September 2011

Keywords:
Renewable energy
Real option analysis
Sensitivity analysis
Wind energy
Investment planning

ABSTRACT

This study examines the feasibility of using a theoretical model and empirical analysis methods to value renewable energy (RE) investment from perspective of real option analysis (ROA). Based on use of a ROA approach, the RE value is evaluated with respect to its ability to conform to the main sensitivity analysis of RE investment, as well as an empirical method devised to value RE investment by using actual data. The economic intuitiveness underlying the decision-making process for RE investment is elucidated, while empirical analysis is performed to demonstrate the effectiveness of the options value embedded in current development planning in Taiwan for wind energy. In addition to revealing the advantages of RE development when considering real option, analytical results indicate that ROA is a highly effective means of quantifying how investment planning uncertainty (including managerial flexibility) influences RE development. Besides evaluating the value of current RE investment, this study demonstrates that results of the theoretical model, empirical analysis, and sensitivity analysis correlate well with each other. Restated, the value of developing RE increases when increasing the underlying price, time to maturity, risk-free rate, and volatility. Conversely, the value of developing RE decreases when increasing the exercise price.

Contents

1. Introduction

Accelerated growth in fossil energy consumption has diminished rapidly fossil energy reserves worldwide, intensifying stress on current reserves daily due to increased demand. Since the industrial revolution, traditional fossil energy has been explored and extracted in significant amounts, gradually leading to its depletion. Table 1 lists the global reserves and projected years of supply remaining for major fossil energies [1]. Meanwhile, owing to adverse environmental impact caused by application of traditional energies, e.g., climate change, global warming green-house effect, and environmental pollution, reducing dependence on traditional energy sources and mitigating related environmental damage is essential for human survival. Defined as sustainable and clean, renewable energy (RE) can potentially overcome the gradual depletion of traditional fossil energies and their adverse environmental impact, while simultaneously addressing energy sustainability, economic development, and environmental protection-related issues (3E, see Fig. 1). Consequently, advances in RE applications have accelerated in the recent decade [2]. Taiwan is a densely populated island limited natural resources. Energy Consumption Island wide has exploded over the past two decades, i.e.48.04 million kiloliters of oil equivalent (KLOE) in 1989 to 113.09 million KLOE in 2009, representing an average annual growth of 4.37%. Of that in 2009, 96.87% accounted for energy use, and non-energy uses consumed 3.13% [3]. Taiwan went from a supply of 52.88 million KLOE in 1989 to 138.06 million KLOE in 2009, i.e. an average annual growth of 4.92%. Of this total in 2009, indigenous energy contributed 0.63%, and imported energy accounted for 99.37%. Classified by energy, coal contributed 30.45% in 2009, oil constituted

* Corresponding author. Tel.: +886 25865000x819; fax: +886 25867648.
E-mail address: shunchunglee@gmail.com

1364-0321/$ – see front matter
doi:10.1016/j.rser.2011.07.107

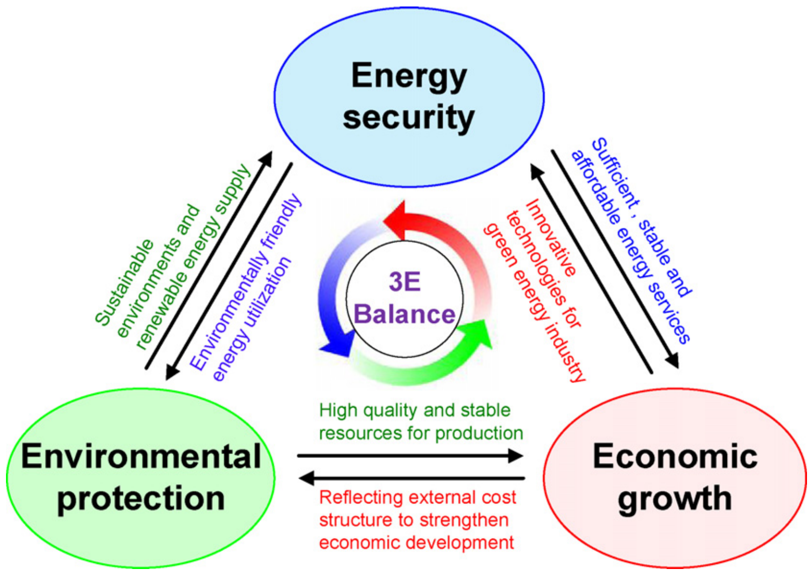

Fig. 1. The relationship of 3E.

51.82%, natural gas shared 8.62%, hydro energy provided 0.26%, nuclear energy provided 8.72%, solar and wind energy provided 0.06%, and solar thermal 0.08% [4].

Characterized as sustainable and clean, renewable energies can potentially overcome gradual depletion of fossil fuels and global warming caused by greenhouse gas emissions [5,6]. Therefore, RE has received considerable attention, with related applications accelerated in recent years [7,8]. To remove barriers to develop RE, the Taiwan Government legislated the "Renewable Energy Development Bill" on July 8, 2009 through a 6-year national plan [9]. According to the legislation, the government may implement measures such as the Feed-in Tariff (FIT) and demonstrations to stimulate the development of RE incentives. The legislation focuses on promoting an ambitious target of achieving approximately 6500–10,000 MW of energy from RE by 2025, which is equivalent to increasing the cumulatively installed capacity of Taiwan power supply from RE to exceed 15% [9]. Additionally, the nationwide power capacity of RE is forecasted to increase up to 10 GW over the next two decades. Hopefully, actively implementing this legislation can achieve the so-called triple-win goal, i.e. reduction in greenhouse gas emissions, enhancement in energy diversity, and promotion of the green energy sector. Unfortunately, as the end 2010, besides hydropower and biomass, Taiwan still lagged far behind its RE goals (Table 2). Clearly, RE development in Taiwan, in addition to relying on intensive governmental promotional efforts, also requires public–private sector collaboration if the 2025 targets are to be met nationwide. Success of this undertaking largely depends on governmental policy support and a relevant legal basis during the early developmental period [10–18]. Nevertheless, governmental subsidies are insufficient. Investment firms must ultimately adopt innovative utilization methods and technologies, capacity expansion to achieve economies of scale, and internalization of the external costs of energy use if they are to fill the cost gap between RE and NRE, thereby enabling RE to compete with NRE in open markets.

RE technology advances are constrained by high research and development (R&D) costs and difficulty of investment recovery, long and deferrable planning processes, high investment risks and uncertain returns, as well as the liberty of decision makers to invest freely. Policy makers can thus exert managerial flexibility to adjust policies appropriately, ensuring that RE development policies meet policy targets. The ability to use real option analysis (ROA) to assess the benefits of RE development policies allows us not only to quantify managerial flexibility neglected by conventional assessment methods, but also minimize the possibility of underestimating policy value. Hence, development policies may capitalize on the options concept to generate value derived from "waiting" in order to reduce uncertainty in policy planning [19]. Nevertheless, interested investors are often deterred from investing not only because of many critical technologies have failed to achieve breakthroughs, but also because of investment risks are difficult to assess, ultimately reducing cost effectiveness in power generation [20].

Therefore, based on ROA, this study evaluates the value of investment opportunities and verifies the sensitivity analysis, which shows the relationship between the value of developing RE and underlying assets, as well as other main option parameters. The rest of this paper is organized as follows. Section 2 provides a literature review. Section 3 describes the methodology of this study. Section 4 presents the parameter collection and empirical results. Conclusions are finally drawn in Section 5, along with recommendations for future research.

2. Literature review

The discounted cash flow method (DCF method) and payback period method (PP method) are the traditional adopted methods for evaluating the value of an investment plan. While pioneering the theory of interest and the value of time, Fisher [21,22] developed the DCF method, which is extensively adopted to evaluate investments and real asset investment decisions. The DCF method includes the net present value method (NPV method) and internal rate of return method (IRR method). This method is characterized by its simple calculation and easily visualized logic. However, its analytical framework and assumptions are based on irreversible and non-deferrable investment. DCF is thus applicable only for evaluating short-term investment projects with low uncertainties. Given its limited flexibility, DCF method is inappropriate for a fluctuating investment climate [23,24]. Table 3 summarizes the merits and limitations of the three assessment methods. As is widely recognized by numerous academics and practicing managers, traditional financial analysis methods for capital budgeting are inadequate, e.g., DCF and NPV [25]. Moreover, the DCF method cannot accurately reflect managerial flexibility in investment

Table 1
Global reserves, production, and availability of major fossil energy resources (end of 2009).

	Oil			Natural gas			Coal		
	Reserves (billion barrels)	Production (billion barrels)	R/P ratio (years)	Reserves (trillion cubic meters)	Production (trillion cubic meters)	R/P ratio (years)	Reserves (billion tons)	Production (billion tons)	R/P ratio (years)
Total North America	73.3	4.89	15.0	9.16	0.81	11.3	246	1.05	235
Total South and Central America	198.9	2.47	80.6	8.06	0.15	53.2	15	0.08	181
Total Europe and Eurasia	136.9	6.46	21.2	63.09	0.97	64.8	272	1.15	236
Total Middle East and Africa	881.9	7.30	120.8	90.94	0.35	259.5	33	0.25	131
Total Asia Pacific	42.2	2.93	14.4	16.24	0.43	37.0	259	4.39	59
Total World	1333.2	29.2	45.7	187.49	2.99	62.8	825	6.93	119

Source: BP [1].

decisions efficiently, possibly underestimating the opportunity and actual value of an investment [26–29]. Importantly, DCF is limited in its inherent role in many project types, e.g., R&D, RE technology, biotechnology, and pharmaceuticals.

In market competition, however, the utility cannot be ensured a fair rate of return. In such a case, the increased degree of uncertainty significantly impacts generation planning. For instance, for unfavorable market conditions, e.g., a lower price for electric power, then a power plant may no longer remain profitable. Such uncertainty implies substantial financial risks in generation planning. Under this new environment towards competition, the following two factors in decision making have become significant, i.e. financial risks and managerial flexibility (e.g., the ability to make mid-course changes such as an additional expansion of generation capacity) [30]. For instance, under uncertain market conditions, expected values such as expected profit and expected rate of return have become less meaningful without the corresponding financial risks. Additionally, under uncertainty, cash flows may differ significantly from what a utility has expected initially. As new information arrives and market condition-related uncertainties are resolved, the utility may adjust its strategy to grasp future opportunities. Under these circumstances, traditional decision support methods are inadequate. For instance, the DCF method selects projects that yield a positive NPV, while the IRR method selects projects that yield a higher IRR than the capital cost. Neither DCF nor IRR, however, addresses financial risks or managerial flexibility.

The ROA concept originated from finance research. While pioneering the real option (RO) analysis method, Myers [31] posited that profits created by cash flow generated from an investment originate from currently owned assets in addition to options for future investment opportunities. Myers pointed out, for the first time, that adopting DCF does not contribute to R&D. A firm that decides to make an irreversible investment exercises an option. The lost option value is an opportunity cost that must be incorporated in the assessment of the investment cost, i.e. an essential feature in explaining the lack of consistency between neoclassical investment theory and investment behavior. The options pricing theory of Black and Scholes (B–S) was subsequently applied to value non-financial or "real" investments planning and acquire real assets with learning and flexibility, such as multi-stage R&D and modular manufacturing plant expansion [32]. In contrast with traditional valuation models of investment decisions, RO models can evaluate managerial flexibility. The most common categories of encountered RO can be broadly classified into seven types [33–35], i.e. option to defer, time-to-build option, option to alter operating scale, option to abandon, option to switch, option to growth, and interaction among multiple RO. Table 4 introduces the general definition of these options and identifies the options for RE projects (i.e. wind energy) in this study.

Several studies have demonstrated that the developing RE value can be evaluated through a ROA. Table 5 summarizes the studies of ROA for RE technologies. For example, Davis and Owens [39] estimated the option value of renewable electric technologies (wind energy) in the face of uncertain fossil fuel prices. That study also analyzed the optimal annual R&D funding allocated to RE by using sensitivity analysis. Siddiqui et al. [42] evaluated the real options value of RE R&D projects under various market risks and energy portfolio and determined the PV of real options. The proposed model considers RE costs, NRE costs, R&D expenditure of RE, abandonment and maintenance costs and RE demand. Kumbaroğlu et al. [44] proposed a policy planning model based on ROA while considering RE and NRE cost, availability factor, capacity factor, learning rates, and construction lead times. Martínez-Ceseña and Mutale [46] proposes an advanced ROA for RE generation projects planning, and illustrates the methodology using variations of a hydropower case study. Furthermore, most cases analyzed are in

Table 2
Current status and future targets for renewable energy development in Taiwan.

Year Renewables	December, 2010		2010		2015		2025	
	Current status				Future targets			
	Installed capacity (MW)	Rate (%)	Installed capacity (MW)	Rate (%)	Installed capacity (MW)	Rate (%)	Installed capacity (MW)	Rate (%)
Hydropower	1977.4	5.1	2168	5.7	2261	5.1	2500	4.47
Wind power	477.6	1.3	980	2.5	1480	3.4	2450	4.38
Solar photovoltaics	22.0	0.0	31	0.1	320	0.7	2000	3.57
Geothermal		–	–	–	10	0.0	150	0.27
Biomass + waste power	825.5	2.03	741	1.9	850	1.9	1400	2.50
Fuel cell	–	–	–	–	–	–	200	0.36
Ocean energy	–	–	–	–	1	0.0	200	0.36
Total	3320.6	3910	4922	8900				
Target share for renewable energy in terms of installed capacity of the total power generation	8.26	10.2	11.1	15.9				

Source: BOEMOEA [3].

industrialized countries or countries that have largely been successful in developing RE. For developing countries and countries beginning to develop RE, in addition to the difficulty in obtaining data, the resulting ROA can easily generate significant errors in interpretation. Previous studies are limited in either only concentrating on the relationship between RE and uncertainty or lacking sensitivity testing of the relationship. Furthermore, technological development of RE are similar to R&D activities in that

Table 3
Merits and limitations of traditional assessment methods.

Method	Merits	Limitations
Net present value method	Time possesses value and reflects all cash flows.	Owing to a potential high uncertainty of the cash flow and discount rate forecasts, forecasting errors lead to erroneous results, and decision-making risk is relatively high.
	The magnitude of economic benefits from an investment plan is considered	When different investment cases entail varying amounts of risk, the NPV method's use of the same lowest rate of return on investment to discount cash flow tends to lead to a bias; different discount rates should thus be adopted.
	NPV represents how an investment plan directly contributes to corporate value, and can accurately represent how it influences stockholder wealth	The NPV method does not reflect high or low cost effectiveness
	The principle of value additivity is compliant, implying that the sum total of a company's value equals the sum of the contributions of its individual independent investment plans	
	Only the NPV method can obtain the optimal decision when an exclusive plan is selected	
Internal rate of return method	Time also possesses value and reflects all cash flows	Since the IRR is a rate, this method does not consider the amount of investment and magnitude of cash flow.
	The magnitude of economic benefit from an investment plan is considered	It not considers the various compensations of individual investment cases.
	The profitability of an investment plan is expressed as a single rate (IRR), which can be compared with other rates	Because IRR is an unknown, analysis may be difficult when an investment plan exceeds two periods in duration, while net cash inflow may occasionally be positive and occasionally negative.
	Profitability is expressed as a rate of return, and can be easily compared with the cost of funds	It may yield an erroneous decision when evaluating an exclusive investment plan
		It makes unreasonable assumptions about the rate of return on reinvestment
		Under circumstances of abnormal cash flow, this method may calculate one or more IRR values that are not consistent with value additivity
Payback period method	It is relatively simple and easy to calculate and understand	Does not assess economic compensation
	It allows the time when the cost of an investment plan is completely recovered to be determined	Does not take the time value of currency into consideration; tends to underestimate payback periods
	It is easy to calculate and understand, as well as capable of assessing the liquidity of an investment plan	Has no absolute standard for determining what the payback period should be in order to obtain the investment plan with the most suitable liquidity rate
		Does not consider whether the plan will still generate long-term cash flow after recovering cost
		Does not consider the influence of the time value of currency (opportunity cost)

Table 4
Definition of the real option.

Types	General definition	Definition for this study
Option to defer	Management holds a lease on (or an option to purchase) land or resources. The lease can wait X years without exercise	The management, who holds the license to build and operate a wind turbine, can defer the plant construction until demand level and/or prices justify developing (short Lead-time attribute). Experience has shown that time works in favor of this production method (production cost has decreased significantly and the process has become competitive)
Time-to-build option	Staging investments as a series of outlays creates the option to abandon the enterprise in midstream if new information is unfavorable. Each stage can be viewed as an option on the value of subsequent stages and valued as a compound option	A wind turbine can be developed in stages) (Modularity attribute), thus allowing for review of the decision to continue with the next stage or not. Short Lead-time is a convenient means of determining whether changes in demand trend or price levels are permanent and responding to the new market conditions with a relevant certainty
Option to alter operating scale	If market conditions are more favorable than expected, the firm can either expand the production scale or accelerate resource utilization and, conversely, if conditions are less favorable. Under extreme conditions, production may be ceased and restarted	If market conditions are more favorable than expected, a wind energy plant can be expanded to take advantage of the real market conditions. If expectations do not measure up realistic conditions, there is the option of reducing the scale of operations or partially decommissioning
Option to abandon	If market conditions decline severely, management can abandon current operations permanently and realize the resale value of capital equipment and other assets on second hand markets	If market conditions decline severely or if the capital equipment becomes obsolete due to technological changes, the management can abandon the wind energy plant to permanently resume any residual value
Option to switch	If prices or demand change, management can adjust the output mix of the facility (product flexibility). Alternatively, the same outputs can be produced by using different inputs (process flexibility)	Not discussed in this study
Option to growth	An early investment, e.g., R&D, is a prerequisite or a link in a chain of interrelated projects, subsequently creating future growth opportunities, e.g., a new product or process. A notable example is an inter-project compound options	Owing to that electricity market enters a new era of deregulation, growth options are considerable and should be considered during appraisal process of the projects. Example, under the recent oil prices shock and the fact that environmental problems become increasingly stressful, wind energy production is a valuable alternative and environmental friendly energy source. Therefore, this market can be expected to expand rapidly
Interaction among multiple real option	Real-life projects often involve a collection of various options. Upward-potential-enhancing and downward-protection options are present in combination. Their combined value may differ from the sum of their separate values, i.e. they interact with each other. They may also interact with financial flexibility options	Not discussed in this study

Source: Kjærland [36]; Lee and Shih [37].

short-term, medium-term, and long-term goals may require decades to achieve. Therefore, not only is the traditional evaluation model unsuitable for investment valuation of energy projects [47], but it fails to reflect the value of RE technology in the highly volatile energy market [48]. The value of an R&D investment project is rarely an immediately realizable return. Rather, profit is typically generated from future investment opportunities after successful R&D [31,49]. Hence, quantifying an investment opportunity is essential for estimating the value of an investment project. ROA is one tool that accurately measures the value of a specific project [24,50–53]. Therefore, based on use of ROA, this study evaluates the value of investment opportunities and verifies the sensitivity analysis that shows the relationship between the value of developing RE and underlying assets, and other main option parameters. This study also assesses value for RE investment when limited data is available by using ROA, especially for the case of RE technology in Taiwan.

3. Methodology

Similar to financial options, ROs have five major components, i.e. underlying price (S), exercise price (K), time to maturity (T), risk-free rate (R_f), and volatility (σ). Table 6 compares financial options and ROs. Table 6 also includes the variable of ROs valuation with respect to developing RE. The project value of the developing RE, S, follows a geometric Brownian motion (GBM):

$$\frac{dS}{S} = \mu dt + \sigma dz_S \tag{1}$$

Table 5
Overview of ROA studies for renewable energy technologies.

Year	Reference	Country
2002	Venetsanos et al. [38]	EU
2003	Davis and Owens [39]	US
2004	Botterud and Korpås [40]	Nordic
2006	Rothwell [41]	US
2006	Wang and Min [30]	US
2007	Kjærland [36]	Norway
2007	Siddiqui et al. [42]	US
2008	Bøckman et al. [43]	Norway
2008	Kumbaroğlu et al. [44]	Turkey
2009	Fuss et al. [45]	IEA
2010	Lee and Shih [19]	Taiwan
2011	Martínez-Ceseña and Mutale [46]	UK

Table 6
Comparison of financial option and real option.

Variable	Description	Financial option	Real option for project's characteristics
S	Underlying price	Stock price: Current value of stock	PV of project's operating assets: This value of the project in place is equal to the expected PV of the stream of profits and/or losses it would generate
K	Exercise price	A fixed share price	Expenditure required acquiring the project's assets: The cost of converting the investment opportunity into the option's underlying asset
T	Time to maturity	Time until the expiration date	Maximum length deferral period: The length of time the investment can be deferred without losing an opportunity
R_f	Risk-free rate	Risk-free rate corresponding to the time to maturity	Time value of money: It is the risk free rate of return, normally the rate of return of the treasury bill or the 10-year government bond
σ	Volatility	The uncertainty of stock price	Risk of the project's assets: It is the uncertainty with respect to the future value of the project's cash flows or else the volatility of the expected return on S

Where μ denotes the instantaneous expected return on the project value; σ represents the instantaneous standard deviation of the proportional changes in the project value, and dz_S refers to the increment of a Wiener process. From the above variable definition, the B–S option pricing model is described by the following formulation:

$$C = SN(d_1) - Ke^{-R_f T} N(d_2) \tag{2}$$

where

$$d_1 = \frac{\ln\left(S/K\right) + \left(R_f + 0.5\sigma^2\right) T}{\sigma\sqrt{T}}$$

$$d_2 = d_1 - \sigma\sqrt{T}$$

Additionally, this study also verifies the sensitivity analysis, which shows the relationship between the value of developing RE and underlying assets, and other main option parameters. Five hypotheses are discussed as follows.

(1) Hypothesis 1: The RE value increases according to an increase in the underlying price S, i.e. $\frac{\partial C}{\partial S} = N(d_1) + S \times \frac{\partial N(d_1)}{\partial S} - Ke^{-R_f T} \times \frac{\partial N(d_2)}{\partial S} > 0$.
(2) Hypothesis 2: The RE value increases according to a decrease in the exercise price K, i.e. $\frac{\partial C}{\partial K} = S \times \frac{\partial N(d_1)}{\partial K} - e^{-R_f T} N(d_2) - K \times \frac{\partial N(d_2)}{\partial K} < 0$.
(3) Hypothesis 3: The RE value increases according to an increase in the time to maturity T, i.e. $\frac{\partial C}{\partial T} = S \times \frac{\partial N(d_1)}{\partial T} + R_f e^{-R_f T} N(d_2) - Ke^{-R_f T} \times \frac{\partial N(d_2)}{\partial T} > 0$.
(4) Hypothesis 4: The RE value increases according to an increase in the risk-free rate R_f, i.e. $\frac{\partial C}{\partial R_f} = S \times \frac{\partial N(d_1)}{\partial R_f} + TKe^{-R_f T} N(d_2) - Ke^{-R_f T} \times \frac{\partial N(d_2)}{\partial R_f} > 0$.
(5) Hypothesis 5: The RE value increases according to an increase in the volatility σ, i.e. $\frac{\partial C}{\partial \sigma} = S \times \frac{\partial N(d_1)}{\partial \sigma} - Ke^{-R_f T} \times \frac{\partial N(d_2)}{\partial \sigma} > 0$.

The following sections describe the data parameter collection and empirical results.

4. Parameter collection and empirical results

Data for wind energy generation in Taiwan were analyzed empirically. Three demonstration systems for wind energy generation in Taiwan are of particular focus. The first one is Mai-Liao Wind Energy Demonstration System, located in Mai-Liao, Yunlin County of eastern Taiwan, operated by Formosa Heavy Industries Company, completed in November 2000, with capacity of 2640 kW. The second one is Chungtun, Penghu Wind Energy Demonstration System, located in Chungtun, Penghu County of southern Taiwan, operated by Taiwan Power Company, which was completed in October 2001 and has capacity of 2400 kW. The third one is Springwind Wind Energy Demonstration System, located in Chupei, Hsinchu County of northern Taiwan, operated by Tien Long Paper Manufacturing Company, with capacity of 3500 kW. The total capacity of above three wind energy system is 8540 kW, which is equivalent to the utility usage of 3000 families. Table 7 lists the relative inputs of ROA. Data were then input into Eq. (2) to obtain the option value for developing RE. Sensitivity analysis was also performed, demonstrating the relationship between the value of developing RE and underlying assets, and other main option parameters.

(1) Underlying price: Estimated NRE costs from weighted average power generation costs (petroleum, coal, natural gas, and nuclear) in 2006, according to the Taiwan Power Company [54].
(2) Exercise price: Estimated RE costs from average power generation costs of Wind Power Demonstration System (Mai-Liao, Chungtun, and Springwind) in 2003, according to the Executive Yuan Nuclear-Free Homeland Commission [55].
(3) Time to maturity: The time to expiration is 10 years, equal to the lowest value of the wind turbine economic life [19].
(4) Risk-free rate: Average 10-year government bond, 1986–1998, according to the Taiwan Futures Exchange [56].
(5) Volatility: Standard deviation of West Texas Intermediate (WTI) historic percentage price movements, 1972–2007 [57].

A positive RO value implies that specific investment planning is an appropriate investment planning under an investment that focuses on benefit-maximizing for the developing RE. Conversely, a negative RO value suggests that a specific investment project is an inappropriate investment under investment that focuses on benefit-maximizing for the developing RE. A situation in which RO value equals 0 implies the break-even point of an investment project. The RO value for developing RE calculated using Eq. (2) is NTD 1.0264 NTD/kWh, where S denotes 1.6803 NTD/kWh, K represents 1.9733 NTD/kWh, T refers to 10-year, R_f is 0.035, σ is 0.50, d_1 denotes 0.9103, and d_2 represents −0.6709. This paper uses the target year stated in the Green Energy Industry Programme proposed by the Ministry of Economic Affairs (MOEA) in 2009 as the investment planning target year in the empirical case to assess the investment value generated by the government policy for wind energy development [58]. The interim government target for developing wind energy is to achieve an installed capacity of 1480 MW,

Table 7
Inputs for ROA calculation.

Variable	Project's characteristics	Value
S	PV of project's operating assets	1.6830 NTD/kWh
K	Expenditure required acquiring the project's assets	1.9733 NTD/kWh
T	Exercise period	10 years
R_f	Time value of money	3.5%
σ	Riskiness of the project's assets	0.50

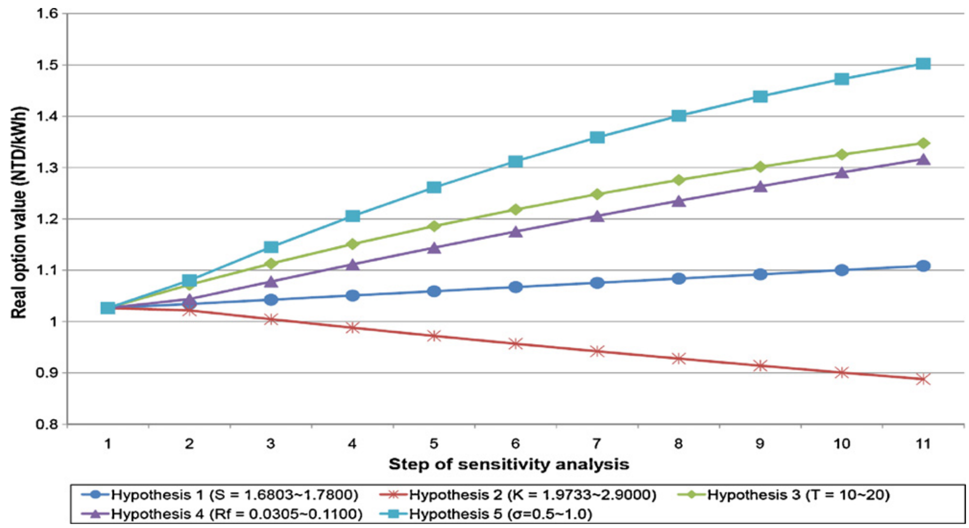

Fig. 2. Impacts of five hypotheses on real option value.

Table 8
Five variables that drive the ROA value and its relationship.

Variable	Impact of ROA value	Notes
S	Positive impact	An increase in the current value of the project increases NPV (without flexibility); the ROA value thus increases as well
K	Negative impact	A higher investment cost reduces NPV (without flexibility), subsequently reducing the ROA value
T	Positive impact	A longer time to expiration allows us to learn more about the uncertainty, subsequently increasing the ROA value
R_f	Positive impact	An increase in the risk-free rate increases the ROA value since it increases the time value of money advantage in deference to the investment cost
σ	Positive Impact	In an environment with managerial flexibility, an increase in uncertainty increases the ROA value

3.4% of total installed capacity by 2015. The value of developing in wind energy is assessed by calculating the NPV, in which a traditional valuation model is used [59]. Of which, NTD −857 million reflects that the policy is unprofitable and inappropriate. However, a situation in which the ROA is adopted for assessment yields the opposite result. The value of developing in wind energy with managerial flexibility is NTD 1519.072 million (1.0246×1480) by 2015. Therefore, the overall investment value for developing RE is NTD 662.072 million by 2015. This value reveals that the project is attractive and appropriate for investment planning. In this case, a high level of uncertainty is a significant factor that increases the RO value. This higher value also originates from the additional value of managerial opportunities and the flexibility embedded in this investment. Additionally, an attempt is made to demonstrate the relationship between the value of developing RE and underlying assets, and other main option parameters by performing sensitivity analysis to elucidate this relation. Fig. 2 summarizes the sensitivity analysis results for the five hypotheses made in Section 3. Table 8 summarizes the relationship between the value of developing RE and five main option parameters.

5. Conclusions

This study established a ROA approach and subsequently performed sensitivity analysis showing the relationship between the value of developing RE and underlying price, exercise price, time to maturity, risk-free rate, and volatility. Furthermore, the above relationships were examined based on empirical data. Analytical results also indicated that the value of developing RE increases with an increase in the underlying price, time to maturity, risk-free rate, and volatility. Conversely, the value of developing RE decreases with an increase in the exercise price. Moreover, the analytical framework of ROA allows us to evaluate volatility, uncertainty, and managerial flexibility in investment planning.

RE is characterized as environmental friendly, diverse in sources, and have predictable costs that are not linked to fluctuations in global oil prices. However, in contrast with their industrialized country counterparts elsewhere that had achieved their industrialization and urbanization without energy security and environmental concerns, Asian countries, particularly those in Southeast Asia, must face the twin threats of energy security and global climate change during their industrialization and urbanization. This poses additional challenges for developing Asian countries because they not only need to seek energy to meet their increasing demand but also, more importantly, must address rising consumption of fossil fuels and the resulting environmental consequences [60]. To meet these challenges, an increasing number of in-depth studies have been conducted on energy policy issues in Asia. However, Asian research is less visible to the outside world, partially because of difficulties in publishing in English. Therefore, this study provides a practitioner's guide to ROA for Taiwan RE industries. Why should ROA be used to evaluate major investment decisions? This may be because ROA values have the flexibility to respond to uncertain events. Conversely, traditional evaluation models lack this ability, ultimately undervaluing everything. ROA is thus more difficult to use, explaining the motivation for this study.

Based on ROA, this study applied the B–S model to incorporate such internal factors as firm decision-making actions and external factors such as oil price fluctuations and other changes in the investment environment. An appropriate options strategy allows the ROA model to reduce investment implementation costs, enhance investment performance, and facilitate an estimation of substantial

benefits created by specific policies. We therefore recommend that the government, relevant energy units, and, RE industries utilize the options strategy planning concept when drafting RE development policies, promotional measures, and investment planning. Doing so helps us to achieve optimal energy conservation and carbon reduction results, ultimately allowing us to realize a low-carbon society in the future.

However, as is well known, RE development is complex with many influential factors [18,19]. Therefore, despite its contributions, this study has certain limitations. One RE type is used for the empirical analysis, owing to unavailable data. Data for related parameters data of the applied methodology, as collected by governmental public data, may influence the reliability of such analyses. However, such data are often beyond the control of the researcher's ability. The accuracy and reliability of the data used also affects the accuracy and application of the analyses performed in this study. Future research should attempt to resolve the above limitations by further improving upon the proposed model.

References

[1] British Petroleum (BP). Statistical review of world energy 2010. Available from: http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622.
[2] Chen F, Lu SM, Chang YL. Renewable energy in Taiwan: its developing status and strategy. Energy 2007;32(9):1634–46.
[3] Bureau of Energy, Ministry of Economic Affairs (BOEMOEA), Executive Yuan, Taiwan, ROC, 2010. Available from: http://www.moeaec.gov.tw.
[4] Bureau of Energy, Ministry of Economic Affairs (BOEMOEA). Energy Statistical Handbook 2009. Taipei: BOEMOEA; 2010. Taiwan, ROC.
[5] Boyle G. Renewable Energy: Power for a Sustainable Future. 2nd ed. Oxford University Press; 2004.
[6] Clift R. Climate change and energy policy: the importance of sustainability arguments. Energy 2007;32(4):262–8.
[7] Arnulf JW. Photovoltaics and renewable energies in Europe. Renew Sustain Energ Rev 2007;11(7):1414–37.
[8] Islam M, Fartaj A, Ting DSK. Current utilization and future prospects of emerging renewable energy applications in Canada. Renew Sustain Energ Rev 2004;8(6):493–519.
[9] Bureau of Energy, Ministry of Economic Affairs (BOEMOEA). Renewable Energy Development Bill. Taipei: BOEMOEA; 2009. Taiwan, ROC.
[10] Liou HM. Policies and legislation driving Taiwan's development of renewable energy. Renew Sustain Energ Rev 2010;14(7):1763–81.
[11] del Río P, Unruh G. Overcoming the lock-out of renewable energy technologies in Spain: the cases of wind and solar electricity. Renew Sustain Energ Rev 2007;11(7):1498–513.
[12] Díez-Mediavilla M, Alonso-Tristán C, Rodríguez-Amigo MC, García-Calderón T. Implementation of PV plants in Spain: a case study. Renew Sust Energ Rev 2010;14(4):1342–6.
[13] Ku SJ, Yoo SH. Willingness to pay for renewable energy investment in Korea: a choice experiment study. Renew Sustain Energ Rev 2010;14(8):2196–201.
[14] Tu W, Zhang LX, Zhou Z, Liu X, Fu Z. The development of renewable energy in resource-rich region: a case in China. Renew Sustain Energ Rev 2011;15(1):856–60.
[15] Saidur R, Islam MR, Rahim NA, Solangi KH. A review on global wind energy policy. Renew Sustain Energ Rev 2010;14(7):1744–62.
[16] Wang Q. Effective policies for renewable energy-the example of China's wind power-lessons for China's photovoltaic power. Renew Sustain Energ Rev 2010;14(2):702–12.
[17] Hwang JJ. Promotional policy for renewable energy development in Taiwan. Renew Sustain Energ Rev 2010;14(3):1079–87.
[18] Lee SC, Shih SH. Enhancing renewable and sustainable energy development based on an options-based policy evaluation framework – case study of wind energy technology in Taiwan. Renew Sustain Energ Rev 2011;15(5):2185–98.
[19] Lee SC, Shih SH. (2010). Renewable energy policy evaluation using real option model – the case of Taiwan. Energ Econ 2011;32(1):S67–78.
[20] Chen YH, Chen CY, Lee SC. Technology forecasting of new clean energy – the example of hydrogen energy and fuel cell. Afr J Bus Manage 2011;4(7):1372–80.
[21] Fisher I. The Rate of Interest: Its Nature, Determination, and Relation to Economic Phenomena. New York: Macmillan; 1907.
[22] Fisher I. The Theory of Interest. New York: Macmillan; 1930.
[23] Dixit AK, Pindyck RS. The options approach to capital investment. Harv Bus Rev 1995;73(3):105–15.
[24] Herath HSB, Park CS. Economic analysis of R&D projects: an options approach. Eng Econ 1999;44(1):1–35.
[25] Wu MC, Tseng CY. Valuation of patent: a real options perspective. Appl Econ Lett 2006;13(5):313–8.
[26] Hayes RH, Abernathy WJ. Managing our way to economic decline. Harv Bus Rev 1980;58(4):67–77.
[27] Hayes RH, Garvin D. Managing as if tomorrow mattered. Harv Bus Rev 1982;60(3):70–9.
[28] Trigeorgis L, Mason SP. Valuing managerial flexibility and strategy in resource. Midl Corp Financ J 1987;5(1):14–21.
[29] Kleczyk E. Risk management in the development of new products in the pharmaceutical industry. Afr J Bus Manage 2008;2(10):186–94.
[30] Wang CH, Min KJ. Electric power generation planning for interrelated projects: a real options approach. IEEE Trans Eng Manage 2006;53(2):312–22.
[31] Myers SC. Determinants of corporate borrowing. J Financ Econ 1977;5(2):147–75.
[32] Black F, Scholes M. The pricing of options and corporate liabilities. J Polit Econ 1973;81(3):637–54.
[33] Brach MA. Real Option in Practice. John Wiley & Sons; 2003.
[34] Copeland T, Antikarov V. Real Options: A Practitioner's Guide. Texere; 2001.
[35] Trigeorgis L. Real Options: Managerial Flexibility and Strategy in Resource Allocation. The MIT Press; 1996.
[36] Kjærland F. A real option analysis of investments in hydropower – the case of Norway. Energ Policy 2007;35(11):5901–8.
[37] Lee SC, Shih LH. The policy planning for renewable energy: a real option based analysis. In: 2009 Cross-Straits Energy Economic Conference. 2009.
[38] Venetsanos K, Angelopoulou P, Tsoutsos T. Renewable energy sources project appraisal under uncertainty – the case of wind energy exploitation within a changing energy market environment. Energ Policy 2002;30(4):293–307.
[39] Davis GA, Owens B. Optimizing the level of renewable electric R&D expenditures using real options analysis. Energ Policy 2003;31(15):1589–608.
[40] Botterud A, Korpås M. Modelling of power generation investment incentives under uncertainty in liberalised electricity markets. In: 6th IAEE European Conference. 2004.
[41] Rothwell G. A real options approach to evaluating new nuclear power plants. Energ J 2006;27(1):37–53.
[42] Siddiqui AS, Marnay C, Wiser RH. Real options valuation of US federal renewable energy research, development, demonstration, and deployment. Energ Policy 2007;35(1):265–79.
[43] Bøckman T, Fleten SE, Juliussen E, Langhammer H. Investment timing and optimal capacity choice for small hydropower projects. Eur J Oper Res 2008;190(2):55–267.
[44] Kumbaroğlu G, Madlener R, Demirel M. A real options evaluation model for the diffusion prospects of new renewable power generation technologies. Energ Econ 2008;30(4):1882–908.
[45] Fuss S, Johansson DJA, Szolgayova J, Obersteiner M. Impact of climate policy uncertainty on the adoption of electricity generating technologies. Energ Policy 2009;37(2):733–43.
[46] Martínez-Ceseña EA, Mutale J. Application of an advanced real options approach for renewable energy generation projects planning, Renew. Sustain Energ Rev 2011;15(4):2087–94.
[47] Tseng CL, Barz G. Short-term generation asset valuation: a real options approach. Oper Res 2002;50(2):297–310.
[48] Deng S-J, Oren SS. Incorporating operational characteristics and start-up costs in option-based valuation of power generation capacity. Probab Eng Inform Sci 2003;17(2):155–81.
[49] Kester WC. Today's options for tomorrow's growth. Harv Bus Rev 1984;62(2):153–60.
[50] Benninga S, Tolkowsky E. Real options-an introduction and an application to R&D valuation. Eng Econ 2002;47(2):151–68.
[51] Herath HSB, Park CS. Multi-stage capital investment opportunities as compound real option. Eng Econ 2002;47(1):1–27.
[52] Lewis N, Enke D, Spurlock D. Valuation for the strategic management of research and development projects: the deferral option. Eng Manage J 2004;16(4):36–48.
[53] Newton DP, Paxson DA, Widdicks M. Real R&D options. Int J Manage Rev 2004;5–6(2):113–30.
[54] Taiwan Power Company, Taiwan, ROC, 2009. Available from: http://www.taipower.com.tw/indexE.htm.
[55] Nuclear-free homeland commission, Executive Yuan. Taiwan's Choice: A Nuclear-Free Homeland. Taipei: EY; 2003. Taiwan, ROC.
[56] Taiwan Futures Exchange. Taiwan, ROC, 2009. Available from: http://www.taifex.com.tw/eng/eng_home.htm.
[57] Oil Information Management and Analysis System, Bureau of Energy, Ministry of Economic Affairs (BOEMOEA), Executive Yuan, Taiwan, ROC, 2009. Available from: http://www.moeaboe.gov.tw/oil102.
[58] Ministry of Economic Affairs (MOEA). Dawn of the Green Energy Industry Program. Taipei: MEA; 2009. Taiwan, ROC.
[59] Kerstin MBG, Joachim MG. Determining the value of drug development candidates and technology platforms. J Commer Biotechnol 2005;11(2):155–70.
[60] Bor YJ, Zhang ZX. Asian energy in the context of growing security and environmental concerns. Energ Econ 2010;32(1):S1–2.